

Refinement and Validation of the Sequence Model

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Award Number: N000140110017

LONG-TERM GOALS

A key goal of the STRATAFORM program has been to use observations of sedimentary processes operating on short time scales to improve our understanding of the development of stratigraphic sequences over time scales of 10^4 - 10^6 years. Tremendous progress in modeling sedimentary processes has been made under the program. However, further work is needed to achieve the goal of a process-based model for predicting the development of stratigraphic sequences. The Post-STRATAFORM modeling effort is focused on two integrative, sequence-oriented modeling systems based on the SEDFLUX and SEQUENCE models.

The key development tasks for the SEQUENCE modeling system include a parameterization of slope and basin processes, linkage of the new slope and basin models into the model system, and model validation. My research contributes to the future development of SEQUENCE in two key areas: establishing rules for slope bypassing and specification of model forcing over long time scales.

APPROACH

Slope Bypassing. An inherent problem with a 2-D model like SEQUENCE is that it cannot directly account for shore-parallel transport of sediment. On continental slopes, sediment-gravity transport moves substantial amounts of sediment through submarine canyons and then redistributed on the continental rise. As a result, sediment supply to a 2-D section across the continental rise may be predominantly derived from the adjacent rise, rather than from the slope above. The new slope model used by SEQUENCE transports a user-specified proportion of the sediment leaving the shelf model directly to the lower slope and rise, bypassing the upper slope. This research focuses on examining the sediment distribution on real continental slopes, rises and basins to determine reasonable values for that user-specified proportion.

A simple estimate of slope bypassing can be obtained by dividing the volume of sediment that has accumulated in the basin and rise by that which has accumulated on the entire margin. A gross estimate of long-term bypassing for a continental margin is thereby obtained from seismic sections with age control from nearby ocean drilling project sites for a variety of passive continental margins. This can be used to provide typical values for continental slope bypassing. Variations in these values can be assessed over space, by looking at results from a variety of margins, and over time, by comparing slope and basin sediment accumulation for the same margin over different periods of time. Long-term bypassing rates estimates would focus on passive margins, where structural deformation

does not interfere with the recognition of the ages of the sediments. The sediment budgets of active margins, however, would also be studied, but over shorter (e.g. late Pleistocene) time scales.

Long-Term Forcing. Many factors that can be regarded as constant over short time scales become variables in long-term simulation. In order to pursue long-term simulations, we must address two important questions: 1) What was the climate like during the time being simulated? and 2) How do changes in climate translate into SEQUENCE model parameters? The first question was addressed by an examination of regional pollen records, faunal data, and the predictions of Global Climatic Models for the New Jersey and Eel Margin sites. The impact of climatic change on sediment supply is modeled in the RIVER component of SEDFLUX. There are few direct ways of estimating past wind speeds and storm frequency, but some estimates can be obtained from climatic models. The SLICE model, developed by Chris Reed and Alan Niedoroda of Woodward-Clyde is a physically-based model that can be driven directly by wind and wave forcing, and validated against tripod data. Using SLICE, simulations of long series of storms with varying wave heights can be used to determine the shelf profile and sediment distribution resulting from varying wave climate. These results, in turn, can be used to estimate the diffusion coefficients used in the SEQUENCE model to simulate varying wave conditions.

WORK COMPLETED

The sediment bypassing estimates obtained in FY01 for the continental margins of Gabon, Argentina, and southeast Greenland were reconsidered to account for biogenic carbonate, using carbonate percentages from nearby ODP sites. These three sites had been chosen to represent passive margins with differing climatic conditions, sediment inputs, and slope angle. Southeast Greenland has an extremely steep slope angle and a dominantly glacial sediment input. Argentina has a moderate slope angle and climate and an extremely wide shelf. The Gabon example represents a comparatively gentle slope angle, with a very high riverine sediment input. Peru and northern California were chosen to represent active continental margins. Since much of the basin sediment on active margins winds up in the subduction complex, where stratigraphy is difficult to unravel, only Quaternary sedimentation rates were considered for those margins.

Paleoclimatic data was studied for both the northern California and New Jersey study areas. Although previous work on the northern California margin has used data based on cores from the Sierra Nevadas, Davis (1999) noted that the climate of the Great Basin and Sierra Nevadas did not follow the same temporal pattern as coastal California. Hence, the long core from Clear Lake (Adam et al., 1981) was selected as a basis for work on future simulations. Millennial-scale variability of the type described for the Oregon margin by Pisias et al. (2001) could be imposed on the simulations, as well. For the New Jersey margin, the pollen diagrams and modern vegetational analogs from Groot et al. (1995) based on the AMCOR sites could be used as the basis for simulations.

Experiments were undertaken using the SLICE model for a simplified cross-shelf profile based on the S-Line on the Eel Margin. After some experimentation, a baseline simulation was chosen using a series of real storms, a constant sediment input, and three grain sizes. Settling velocities were based on the data for Quartz spheres of Rouse (1937) and critical shear stresses for each grain size based on ASCE Task Committee (1967). Simulations were run with different frequencies and intensities of storm events.

RESULTS

For neither the Greenland margin, nor the Gabon margin did biogenic carbonate significantly alter the results. For ODP sites in the Greenland region, only sites very close to the mid-ocean ridge had carbonate contents averaging greater than 10%. Most of the basin floor near Gabon is below CCD, and therefore has little carbonate. Carbonate contents are quite high on the ocean floor off Argentina, however, so as much as 75% of the sediments in the basin in this area may be biogenic carbonate. Even that value, however, would indicate that roughly 64% of the detrital sediment that reached the shelf edge since the Cretaceous had been transferred to the basin.

Results from active margins did not demonstrate the consistent pattern of high bypassing rates that emerged from studies of the passive margins. For northern California, sedimentation rates of greater than 0.1 mm/yr at great distances offshore in the Gorda Basin (e.g. site 1020, Lyle et al., 1999), indicated that slope bypassing was considerable there. However, along at least some parts of the Peru Margin, Quaternary sediments were predominantly deposited in forearc basins on the slope, rather than in the trench (Ballesteros et al., 1988).

A baseline simulation using the grain sizes 3.3ϕ , 4.8ϕ , and 6.3ϕ was selected. The first was chosen because it approximates the average size reported from a box core at a water depth of 38 m on the Eel Shelf (Bouchard and Borgeld, 1988). The baseline simulation produced a deposit that had a sand/silt transition (or “mud line”) at approximately 5.7 km offshore (44 m water depth; Figure 1), and reached a maximum thickness of 32.5 cm at 10.4 and 11.1 km offshore (67-70.5 m; Figure 2). The sand/silt transition and zone of maximum deposition on the Eel Shelf is approximately the same (Sommerfield and Nittrouer, 1999).

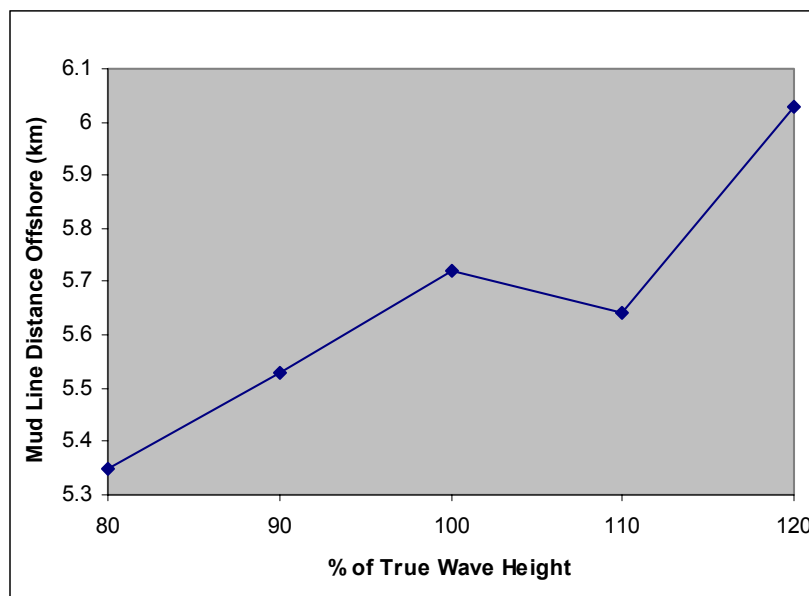


Figure 1. Distance offshore where mean grain size exceeds 4ϕ for different wave heights. 100% indicates the wave height used in simulation is from real storm data, while others are simulated runs with increased or decreased wave heights.

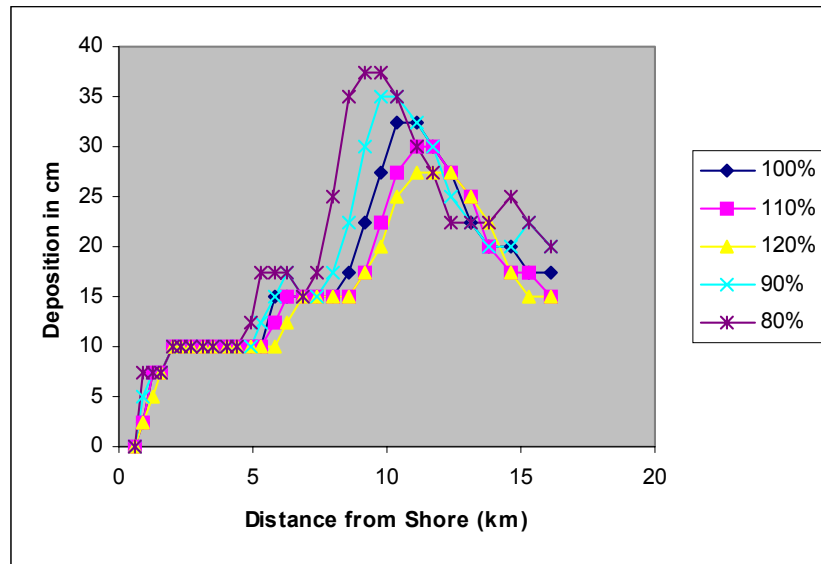


Figure 2. *Net deposition during simulated series of storms along a cross-shelf transect. . 100% indicates the wave height used in simulation is from real storm data, while others are simulated runs with increased or decreased wave heights.*

Other simulations were run with the same data, but with wave heights increased or decreased by up to 20% from the real storm data, so as to simulate climatic conditions that were more or less severe than the present day. The distance offshore to the sand/silt transition increased with increasing wave height (Fig. 1). The offshore distance to the locus of deposition also increased with increasing wave height (Fig. 2), while sediment deposited on the shelf decreased with increasing wave height. Therefore, shelf bypassing was greater with increased wave height.

IMPACT/APPLICATIONS

Further work this year appeared to confirm the idea that slope bypassing is very significant on passive margins, even accounting for the large proportion of biogenic carbonate in basinal sediments off of Argentina. Long-term numerical simulations of continental margins should reflect this, although bypassing may not be uniformly high; some material may temporarily deposit on the slope then be transported to the basin later through regrading. On active margins, bypassing can be considerable, as it is in northern California even during highstands in sea level (Sommerfield and Nittrouer, 1999), but due to the topographic complexity resulting from tectonics, sediment may instead accumulate in slope basins.

The SLICE simulation results showed that increased wave height led to transport of coarser-grained material further offshore, and more offshore transport in general. In itself, this is not a particularly remarkable result, as this is precisely what one would expect. The principal impact of this work is that it shows that SLICE can be run for long enough time periods to provide calibration data for FACIES and SEQUENCE. While the morphodynamic model incorporated in SEQUENCE has always been able to simulate a deeper shelf profile to reflect stronger wave conditions, the SLICE model provides us with a way of constraining exactly how much the equilibrium profile should be varied in order to provide simulations with different wave conditions. Additional work will enable the effects of grain

size distribution, currents, and tides (already simulated by SLICE) to inform our choice of diffusion coefficients for SEQUENCE.

RELATED PROJECTS

This work ties in closely with Michael Steckler of Lamont-Doherty, who has written most of the SEQUENCE model code, and has provided the framework for further development of the model. The slope and basin sediment budget work will help him to choose realistic slope bypassing values for the model. It also ties in with Alan Niedoroda and Christopher Reed of Woodward-Clyde who have developed the SLICE model and worked on calibrating it against tripod and storm data from the northern California margin. Finally, further work with SLICE will enable better choices of parameters for the FACIES model (being developed by Donald Swift and others at Old Dominion) and the large-scale SEQUENCE model.

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